Studies on Explosion II On the Measurement of the Dynamic Pressure Caused by Explosion of Powders

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Bulletin of the Disaster Prevention Research Institute, Vol. 15, Part 3, No. 97, March, 1966

Studies on Explosion II

On the Measurement of the Dynamic Pressure Caused by Explosion of Powders.

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(Manuscript received January 13, 1966)

Abstract

Smokeless powders such as nitrocellulose containing nitroglycerine have been used for common propellants. Recently, these powders have also been used as the propellant of rivet steels. The efficiency of a rivet ejector is mainly influenced by the exploding properties of powders. In this respect, we especially measured the dynamic pressure caused by the explosion of powders, and discussed the relation between the dynamic pressure and the several properties of these powders such as particle size, particle from, and surface conditions of particles.

We further discussed the initiating methods of these powders. From the results of these expariments, we recognized the following facts:

(1) The wave form of the dynamic pressure caused by the explosion of powders is scarcely influenced by the components and particle form of these powders, if an explosion is caused in a closed chamber with the loading density of powders of 0.3 g/cc or more.

(2) Reacting period of powders in a closed chamber is not effected by the initiating methods.

(3) Wave form of the dynamic pressure is influenced by the state of the closed chamber.

The details of the measuring methnds for the dynamic pressure and the overall results of the experiments are shown in this paper.

1. Introduction

To apply powders for propellants, it is considered extremely important to become fully acquained with their exploding or deflagrating properties. In order to investigate the mechanism of explosion and the initiating methods of powders, it is also important to make research into the dynamic pressure caused by explosion.

It is needless to say from the thermodynamical view point that the mechanism of chemical reaction is usually discussed on the basis of the results of measurements of pressure and temperature. In the case of the fast reaction, such as that of powders or explosives, however it is generally difficult to take proper measurement of the temperature caused by the reaction. Therefore the measurement of dynamic pressure is a very important clue and means to account for aspects of explosion.

Along this line of thoughts, we constructed two pressure gauges: One with an elastic steel plate and another with barium titanate for direct measurement

of the exploding pressure, and then, we evaluated the measuring methods of dynamic pressure under various conditions. Further, we discussed the relations between the state of dynamic pressure caused by the explosion of powders and their properties.

2. Principles of measurement of dynamic pressure

Several kinds of manometer such as Bourdon's tube, Pitot bube and mercury column have been used for the measurement of hydrostatic pressure. While the blastmeter has been widely used for the dynamic pressure measurement, the measuring methods with these manomters are sufficient for the static pressure, because, the responsiveness of these manometers for pressure can be left out of consideration.

However the above enumerated methods are not usable for the continuous dynamic pressure measurement, as the time responsiveness of manometers cannot be neglected and, in addition, the time responsiveness is an important factor for the decision of the measurable limits of these pressure gauges.

It has been recognized that the responsive time of the pressure gauge must be infinitesimal in comparison with the reacting period or reacting time of powders or explosives. The reacting time shows the period of pressure development when the reaction of the materials (such as powders) are initiated and come to a steady state.

As the period of pressure development caused by explosion of powders is accepted to be 1 ms or below, the responsive time of the continuous pressure gauge used for explosion of powders should be within 1 ms.

It is customary in the continuous pressure measurement for the pressure to be transformed into some other measurable value resulting from the pressure, for instance, the value of the strain in the elastic zone of a certain material or the value of piezoelectricity. Further, it is generally convinient to measure these transformed values with electric or electronic equipment such as a cathode ray oscillator.

Using the elastic steel plates and piezoelectrical materials for the transforming elements of pressure, we constructed pressure gauges, the details of which are shown in the next paragraph.

3. Measuring methods

In this measurement of exploding pressure, we adopted two methods : one is the method using elastic steel plates for the transforming elements, and the other is by means of barium titanate which is piezoelectric.

3-1 Pressure gauge with elastic steel plates

The pressure gauge with elastic steel plates consists of a main body, a plate supporter, a rear supporting cap, an elastic plate and an electrode as shown in Fig. 1. The main body, plate supporter and rear supporting cap are made of iron-chromium steel and the elastic plate is of iron. Young's modulus of this plate is 2.2×10^6 kg/cm^2 and the plate is 0.8 mm or 1.6 mm in thickness. The capacity of the exploding chamber is 0.17 cm^3. The mechanical strength of this equipment is designed to withstand a pressure of more than 4,000 kg/cm^2.

The elastic plate fixed on its border shown in Fig. 2 is depressed toward the electrode by the exploding pressure. The maximum depression in the central point of the plate naturally occurs in the direction of the acting pressure and the grade of the depression is in proportion to that of the acting pressure in the elastic zone. The relation between the depression and the acting pressure is shown by the next proportional equation.

$$W = Pa^4/64D, \qquad D = Eh^3/12(1-\mu^2)$$

In the above equation, W is the maximum value of the depression in the

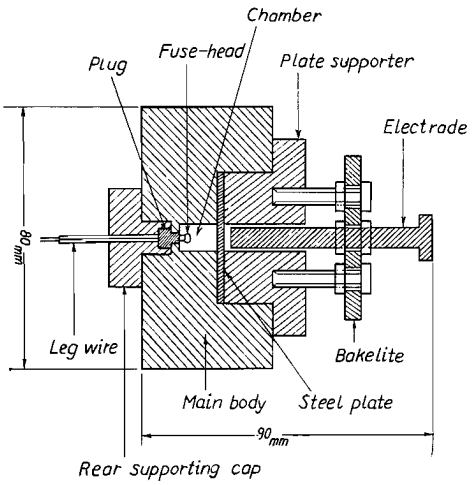


Fig. 1. The equipment of pressure measurement using an elastic steel plate.

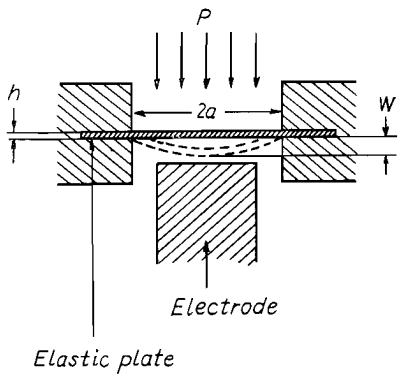


Fig. 2. Depression of the elastic steel plate.

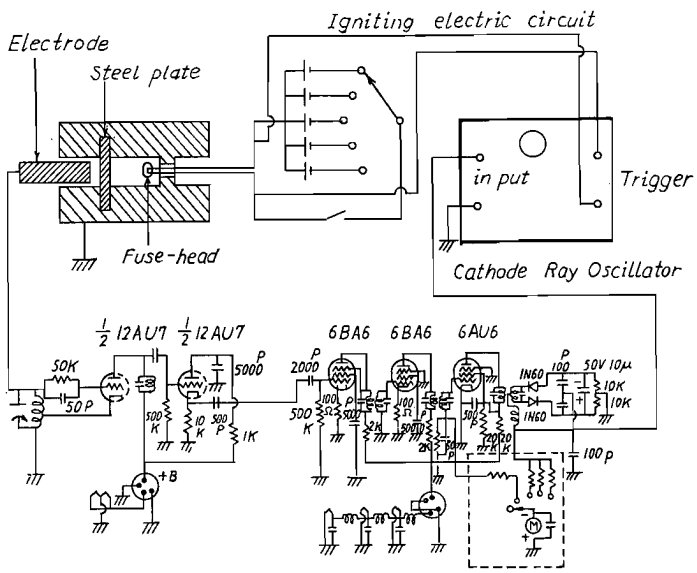


Fig. 3. Electric circuit.

central point of the plate, h is the thickness, a is the radius, E is the Young's modulus and μ is the Poisson's ratio of the plate respectively.

In the meantime, the electric capacity between the elastic steel plate and the electrode shown in Fig. 1 varies with the depression caused by the pressure (P), as the capacity is the function of the distance between the steel plate and the electrode.

Therefore, the exploding pressure in a closed chamber can be measured from the variation of the voltage caused by that of electric capacitance in the electric circuit shown in Fig. 3. In using this electric circuit, it is important to keep the relation between the measuring voltage and the variation of the capacitance in a linear condition.

In this experiment, we measured the voltage with a Cathode Ray Oscillator and, by connecting the oil pressure pump to the exploding chamber, obtained the calibration curve shown in Fig. 4. The calibration curve shows the relation between the measured voltage and the value of hydrostatic pressure in the oil pump.

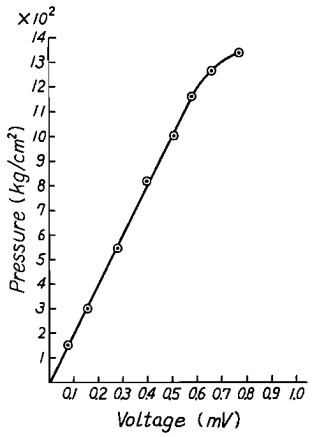


Fig. 4. Calibration curve.

From these data we recognized that the relation between the measured voltage and the pressure value was linear, if the pressure was within 1,200 kg/cm², and that the depression of the steel plate was caused within the elastic zone of its plate, which is suitable for continuous pressure measurement.

In this exploding pressure measurement, the value of exploding pressure of powders was estimated from the static pressure value represented by this calibration curve.

3-2 Piezoelectric pressure gauge

The piezoelectric pressure gauge is shown in Fig. 5. This equipment consists of a main body, two pistons, two piezoelectric elements, two supporting copper springs, two plugs and a rear supporting cap. The main body and rear supporting cap are made of iron-chromium steel and the pistons are of iron steel. The plugs are the same kind as those used in automotive engines. Barium titanate is used for the piezoelectric transforming elements, which are supported by the copper springs in the oil chambers. Two iron steel pistons form partitions between the oil chambers and the exploding chamber.

The capacity of the exploding chamber is designed as 0.34 cm³. As each oil chamber is compressed by pressure from the exploding chamber, the capacity of exploding chamber increases at the ratio of 0.05 cm³ per 1,000 kg/cm³, which is calculated from the compressibility of the oil used.

The piezoelectric transforming elements are discoid as shown in Fig. 6 and generate electricity by pressure. The relation between the generating voltage and the acting pressure is shown in Fig. 7. In these experiments, we used this relation for the measurement of pressure.

We measured through such an electric circuit as is shown in Fig. 8., the

generating voltage of the piezoelectric elements with Cathode Ray Oscillator. In the circuit, time constant is 1.1 s, which is sufficient for the time required for pressure development.

3-3 Ignition methods

In order to ignite powders, we adopted electric ignition system using fuse-heads shown in Fig. 9.

The igniting electric circuit is shown in Fig. 3 and its electric resistance is

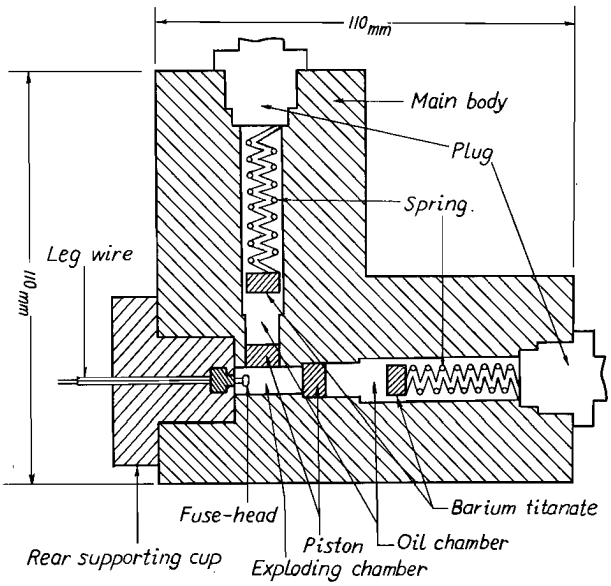


Fig. 5. The equipment of pressure measurement using piezoelectric elements.

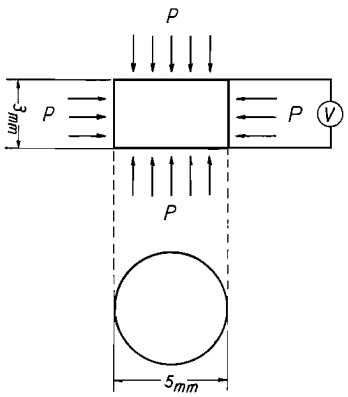


Fig. 6. Piezoelectric element.

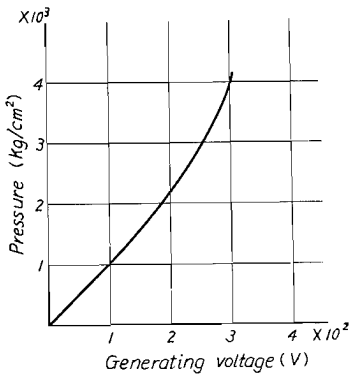


Fig. 7. Relation between generating voltage and pressure.

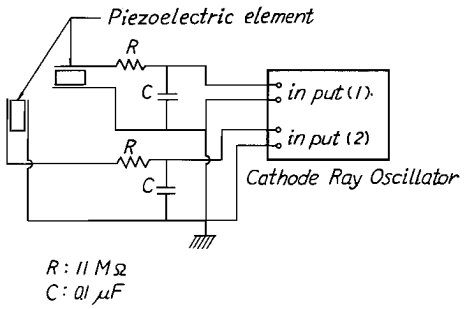


Fig. 8. Electric circuit.

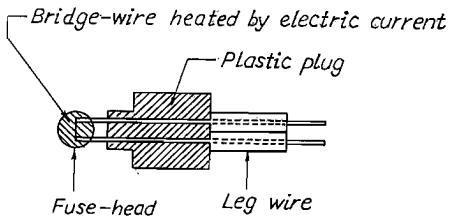


Fig. 9. Fuse-head.

approximately 1.2 Ω.

4. Samples

4-1 Samples of powders

Samples of powders are shown in Table 1.

4-2 Samples of fuse-heads

Samples of fuse-heads are shown in Table 2.

TABLE 1.
Samples of powders.

Sample No.	Ingredients (%)		Particle size (mesh)	Particle form
	Nitroglycerine	Nitrocellulose		
1	40	60	+35	Plate
2	40	60	−35	Plate
3	0	100	+35	Plate
4	0	100	−35	Plate
5	10	90	+35	Spheroid
6	10	90	−60	Spheroid
7	20	80	+35	Spheroid
8	20	80	−60	Spheroid
9	30	70	+35	Spheroid
10	30	70	−60	Spheroid
11	40	60	+35	Spheroid
12	40	60	−60	Spheroid

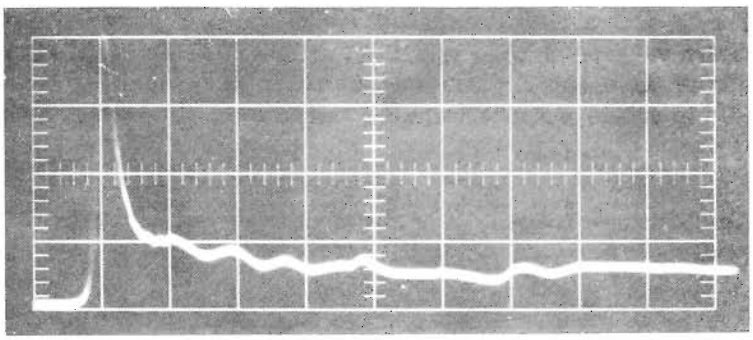
TABLE 2.
Samples of fuse-heads.

Sample No.	Sign	Chemical composition of fuse-head
1	RF	barium nitrate, tricinate, tetracene, ferrosilicon
2	DDNP	diazodinitrophenol
3	1S	diazodinitrophenol, potassium perchlorate

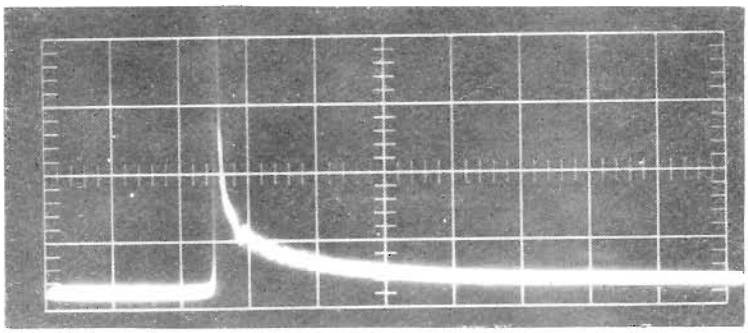
The total weight of chemical composition of fuse-head is about 10 mg.

5. Results of experiments

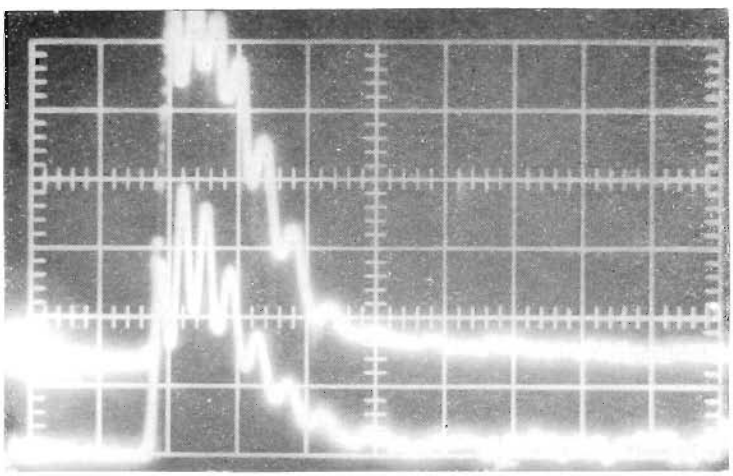
Example of pressure wave forms are shown in Photos 1, 2 and 3. Photos 1 and 2 show the results of the measurement using the pressure gauge with an



Vertical axis : 200kg/cm²/cm Lateral axis . 1ms/cm
Photo. 1. An example of pressure wave form.



Vertical axis . 200kg/cm²/cm Lateral axis : 10ms/cm
Photo. 2. An example of pressure wave form.



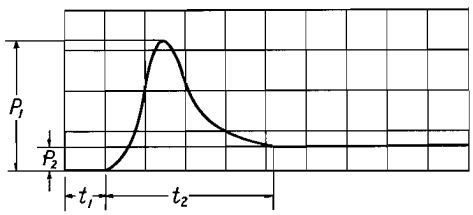
Vertical axis : 760kg/cm²/cm Lateral axis : 1ms/cm
Photo. 3. An example of pressure wave form.

elastic steel plate as described in sub-paragraph 3-1, and Photo 3 was obtained from the piezoelectric pressure gauge as explained in sub-paragraph 3-2.

In the wave form shown in Fig. 10 which represents the general wave form obtained from these measurements, t_1 shows the initiating time, t_2 shows the reacting time, p_1 shows the maximum pressure value and p_2 stands for the steady pressure value after the exploding reaction of the powders.

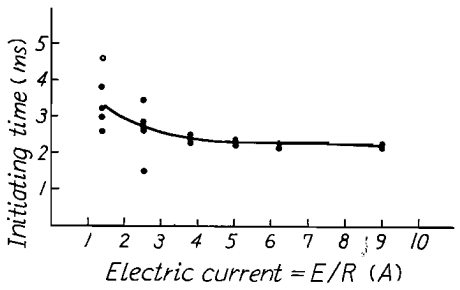
The results of these experiments are shown in the sub-paragraphs below. Those results in sub-paragraphs from 5-1 to 5-3 were obtained by the pressure gauge with elastic steel plate and those in sub-paragraph 5-4 were obtained by the piezoelectric pressure gauge.

5-1 Relations between initiating time and electric current flowing through the ignition circuit with fuse-head (Fig. 11)



t_1 : Initiating time
t_2 : Reacting time
P_1 : Maximum pressure value
P_2 : Steady pressure value

Fig. 10. General wave form.



Fuse-head : Sample No.2 (DDNP)
Powder : Sample No.1
E : Initiating voltage
R : Electric resistance of igniting circuit (1.2Ω)

Fig. 11. Relations between initiating time and electric current.

TABLE 3.
Initiating time (ms).

Fuse-head	RF	DDNP	1S
Initiating voltage : 6V	1.2	2.0	4.3
	1.3	1.5	5.5
	1.5	2.6	6.0
Resistance of igniting circuit : 1.2Ω	1.2	2.2	6.9
	1.5	2.5	5.0
	1.4	2.8	4.2
Powder : Sample No. 1	2.0	2.3	3.6
	1.3	—	4.8
Average	1.43	2.27	5.0

TABLE 4.
Relations between maximum pressure and particle size and other properties.

Samples of powder			t_1	p_1	t_2	p_2	Conditions of measurements
No.	Ingredients of nitrogrlycerine	Particle size	(ms)	(kg/cm²)	(ms)	(kg/cm²)	
	(%)	(mesh)					
1	40	+35	1.0	800	6.5	95	Fuse-head : RF
2	40	−35	1.0	840	5.0	100	Loading density : 0.3 g/cc
3	0	+35	1.3	1080	7.5	80	
4	0	−35	1.1	1180	6.5	95	Initiating voltage : 7.5V
5	10	+35	1.7	840	7.0	93	
6	10	−60	1.1	900	6.0	93	Resistance of igniting circuit : 1.2Ω
7	20	+35	1.1	980	5.5	97	
8	20	−60	1.0	1000	5.0	96	
9	30	+35	1.1	940	5.3	105	
10	30	−60	0.9	1000	5.0	100	
11	40	+35	0.6	820	5.6	95	
12	40	−60	0.5	880	5.4	110	

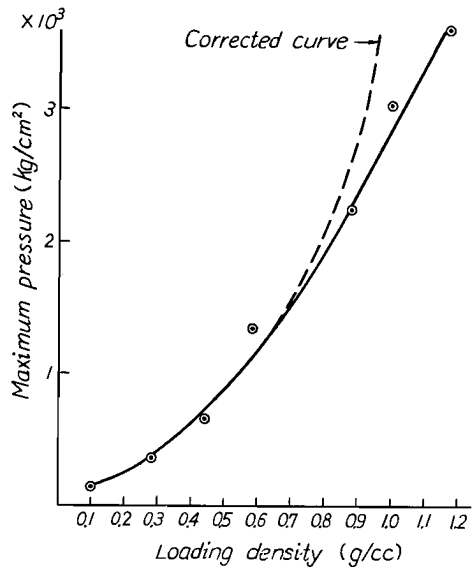


Fig. 12. Relations between maximum pressure and loading density.

5-2 Relations between kinds of fuse-heads and initiating time (Table 3)

5-3 Relations between maximum pressure and particle size and other properties (Table 4)

5-4 Relations between maximum pressure and loading density (Fig. 12)

6. Evaluation of measuring methods

By means of the pressure gauge with the elastic steel plate, it is impossible to measure the continuous exploding pressure, when its maximum value is more than 1,200 kg/cm^2, for, once the elastic steel plate is deformed in its plastic zone by a high pressure, it does not return to the original state as described in paragraph 3.

Although the resonance frequency of the steel plate is 3,000 cycles in its elastic zone by theoretical calculation, this calculated value is not adoptable if the deformation is caused in its plastic zone.

Therefore, the pressure gauge with elastic plate is usable only for the measurement of a pressure which causes the depression of the plate in its elastic zone. The time responsiveness of the pressure gauge is suitable for the exploding pressure continuing for more than 1 ms, as shown in paragraph 5.

In the estimation, by the piezoelectric pressure gauge, of the exploding pressure in the chamber with an assumed constant capacity, the unavoidable increase in the capacity by explosion must be taken into consideration and the measured pressure must be corrected based on the increment. The resonance frequency of the vibratory system in the gauge consisting of an exploding chamber, a piston and an oil chamber, is 2,500 cycles by the measurement.

The time responsivness of this pressure gauge can be improved, as the resonance frequency of barium titanate is as high as 500 kc/s which shows the capability of improving the time responsiveness of the piezoelectric pressure gauge.

7. Consideration

7-1 Initiating time and electric current

From Fig. 11 in subparagraph 5-1, we observed that the igniting time using the same kind and same weight of fuse head became stable when the electric current was 4 A or more, and it was unstable when the electric current less than 4 A was used. From these facts, it is recognized that the priming energy for a fuse head with more than a certain energetic value is required in order to get a stable initiating time.

7-2 Influence on initiating time by the kinds of fuse head

From Table 3, we know that the average initiating time is 1.43 ms when RF-priming composition is used for fuse heads, 2.27 ms in the case DDNP-priming composition and 5.0 ms when 1S-priming composition is used.

Therefore, it is recognized that the initiating time or the starting period of ignition can be controlled by selecting the kind of priming composition used for the fuse head.

7-3 Maximum pressure and particle size

From Table 4, it is noticed that the maximum pressure caused by explosion is influenced by the particle size of powders, even if the loading density it kept constant. The smaller the particle size is, the higher the maximum

pressure becomes. From Table 4, we recognize that the maximum pressure was scarcely influenced by the particle form, and also wave forms could scarcely be influenced by such properties as particle size and form.

From these facts, it is recognized that the maximum pressure of explosion depends mainly on the particle size of powders, when the same kind of powders are ignited in a constant loading density.

7-4 Maximum pressure and loading density

From Fig. 12, we know that the maximum pressure in the closed chamber with an assumed constant capacity was influenced by the loading density. The larger the loading density is, the higher the maximum pressure becomes. The measured maximum pressure value in closed chamber agrees with that from thermodynamical calculation. We further noticed that the maximum pressure was influenced by the condition of the closed exploding chamber.

Therefore, from the above facts, it is recognized that the condition of the exploding chamber is one of the most important factors for the effective utilization of powders for propellant.

8. Conclusion

In these experiments, we recognized that these above described pressure gauges were usable for the continuous exploding pressure measurement of powders, and that the time responsiveness of these pressure gauges were adequate to acquire the time-pressure curve of powders.

From the results of these exploding pressure measurements, we came to the conclusion that the priming energy for the fuse head, and the kind of fuse head were the main factors deciding the initiating time, and that the maximum pressure in closed chamber could be influenced by the loading density and the condition of closed chamber. Also, it was recognized that the wave forms of exploding pressure were influenced by the condition of the exploding chamber, but were scarcely influenced by such properties as particle size and particle form of powders.

In these experiments, we did not pay much attention to the influences by the thermal effects upon the explosion. We are now anxious to make further reserches into the mechanism of the exploding reaction of powders from the view poin of thermal measuerment.

Acknowledgements

The authors are greatly indebted to Professor Ichiro Ito for his instruction during this experiment, and also we offer our thanks to Mr. Nobuo Fujita, superintendent, Nibuno plant, Nihon Kayaku Co., Ltd., for his cooperations in presenting us with the necessary samples and materials. Also, for direct assistance in the experiment, our thanks are due to Mr. Nobuo Yoshida, engineer, Nibuno plant, Nihon Kayaku Co., Ltd.

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